

Subterranean Biodiversity of Arkansas, Part 1: Bioinventory and Bioassessment of Caves in the Sylamore Ranger District, Ozark National Forest, Arkansas

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Abstract

Inventory and assessment of subterranean ecosystems of the Sylamore Ranger District (within Baxter, Marion, Searcy, and Stone counties), Ozark National Forest, was performed 2000 to 2002. The Sylamore District, completely underlain in karst topography (occurring in Mississippian to Ordovician carbonates), contains approximately 10% of the known caves in Arkansas. Thirty-five sites were inventoried, six of which were sampled for environmental quality. These were combined and analyzed with previous studies, creating a database of 1,238 total species occurrences, 230 species, and 61 total sites. Most common were cave crickets, pipistrelle bats, woodrats, mosquitoes, and spiders. Fourteen species obligate to caves or groundwater were found, including four new to science, although a collector's curve showed that sampling effort to date has not reached maximum species richness. Richness was significantly greater in caves developed in Ordovician carbonates, in caves with organic inputs (especially bat guano), and as cave passage length increased. Richness was not significant between watersheds (Buffalo versus White Rivers), nor by water resource, nor by degree of recreational use. Caves were ranked by passage length, total and obligate richness, and overall biological significance. Blanchard Springs Caverns ranked highest and is the most biologically rich cave in Arkansas with 96 total and nine obligate species. Recommendations include continuation of physical and biological inventories, increased protection of high-ranking sites, and increased public education/outreach. The US Forest Service has invested 0.6 million dollars in cave research, monitoring, and protection on the Sylamore District to date.

Introduction

The subterranean fauna of Arkansas are inadequately documented and protected, yet are important for many reasons. These animals are extremely rare and highly endemic, and are a significant part of the natural heritage of the region and nation. In the United States, cave-limited fauna (trogllobites) and ground-water-limited fauna (stygobites) represent more than half of the imperiled (heritage ranks of G1 and G2) species listed in the Natural Heritage Program, yet less than 4% are under federal protection (Culver et al., 2000; NatureServe, 2002). Furthermore, these animals, with their unique morphological adaptations to subterranean habitats, are important subjects of medical and evolutionary research. These animals can also serve as ground water quality indicators (Malard et al., 1996), and ground water is a major water resource for communities, agriculture, and industry in Arkansas. To address these data deficiencies, a regional inventory of subterranean habitats was initiated by a multi-agency consortium (the Ozark Subterranean Biodiversity Project), the results of which are being presented in this manuscript series. This study focused upon one of the most

cave-dense areas of the Ozark plateaus ecoregion.

Public lands managed by the US Department of Agriculture, Forest Service (USFS) harbor the greatest number of populations of imperiled and endangered species of any federal agency - 40% of imperiled species and 50% of federally listed species (Stein et al., 2000). Of all of the national forests in the US, the Ozark National Forest (ONF) is one of the richest in caves. The Sylamore Ranger District of the ONF (Sylamore District) is located within Baxter, Marion, Searcy, and Stone counties (Fig. 1). It contains the majority of caves on the ONF, and an estimated 10% of all reported caves in Arkansas, a state that is itself very rich in caves, ranking 13th in cave richness by state in the US (Harris, 2003). Thus, the Sylamore District has a unique resource and management challenge with its diversity of subterranean habitats and fauna.

Methods

The objectives of this study were as follows: to bioinventory as many caves as possible in a two-year period, with special focus upon caves containing endangered species; in select sites, assess environmental quality,

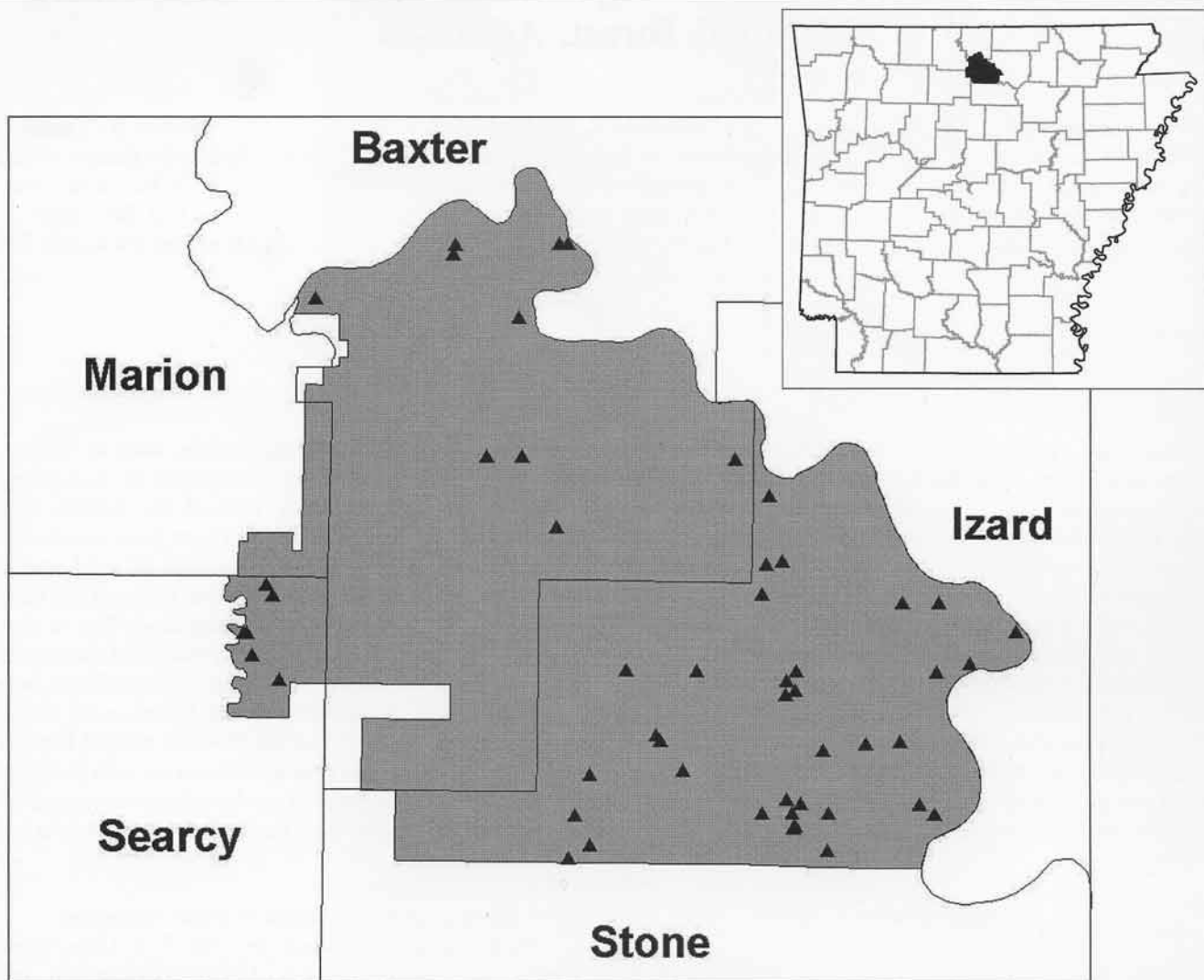


Fig. 1. Inset map shows the location of the Sylamore District within Arkansas. Larger map shows the Sylamore District shaded in gray in relation to Baxter, Marion, Searcy, and Stone counties. Black triangles demarcate the locations of 61 total sites inventoried in this study or previous studies.

focusing upon parameters that might indicate pollution from land-use practices; assemble this new data into a database and, combined with historic information, discern patterns in the distribution of cave fauna, their limiting factors, and the effect of any habitat stressors.

The Sylamore District lies within a dramatic geologic setting – the entire district (*circa* 130,000 acres) lies in karst topography (Fig. 2), a landscape formed by acidic ground water dissolving the carbonate bedrock. This creates a system of voids and conduits that transport enormous amounts of ground water and sediment. The Eureka Springs Escarpment divides the Sylamore District and demarcates the abrupt change from the Springfield Plateau down into the Salem Plateau. Three rivers (the White River, Sylamore Creek, and Big Creek) divide the Sylamore District into the Middle White River Basin and the Buffalo River Basin and

have dissected deeply the plateaus that contain them.

Sites were assessed for the following parameters: level of human visitation - none, little, moderate, and heavy use; presence/absence of vandalism, defined as spray paint or other graffiti, damage to speleothems or fauna, refuse, or smoke damage; presence/absence of organic matter, including leaf and woody debris or guano and other feces; and water resource - dry, drip pool, intermittent stream, or perennial stream. Water samples were taken on 19 - 20 February 2000 at Bald Scrappy Cave, Biology Cave, Blanchard Springs Caverns, Clark Spring, Hell Creek Cave, Nesbitt Spring, and Rowland Cave. Water and sediment samples were taken on 7-8 April 2001 at Blanchard Springs Caverns, Clark Spring, Gunner Cave, Hell Creek Cave, Nesbitt Spring, and Rowland Cave and again on 29 March 2002 at Blanchard Springs Caverns, Clark Spring, and

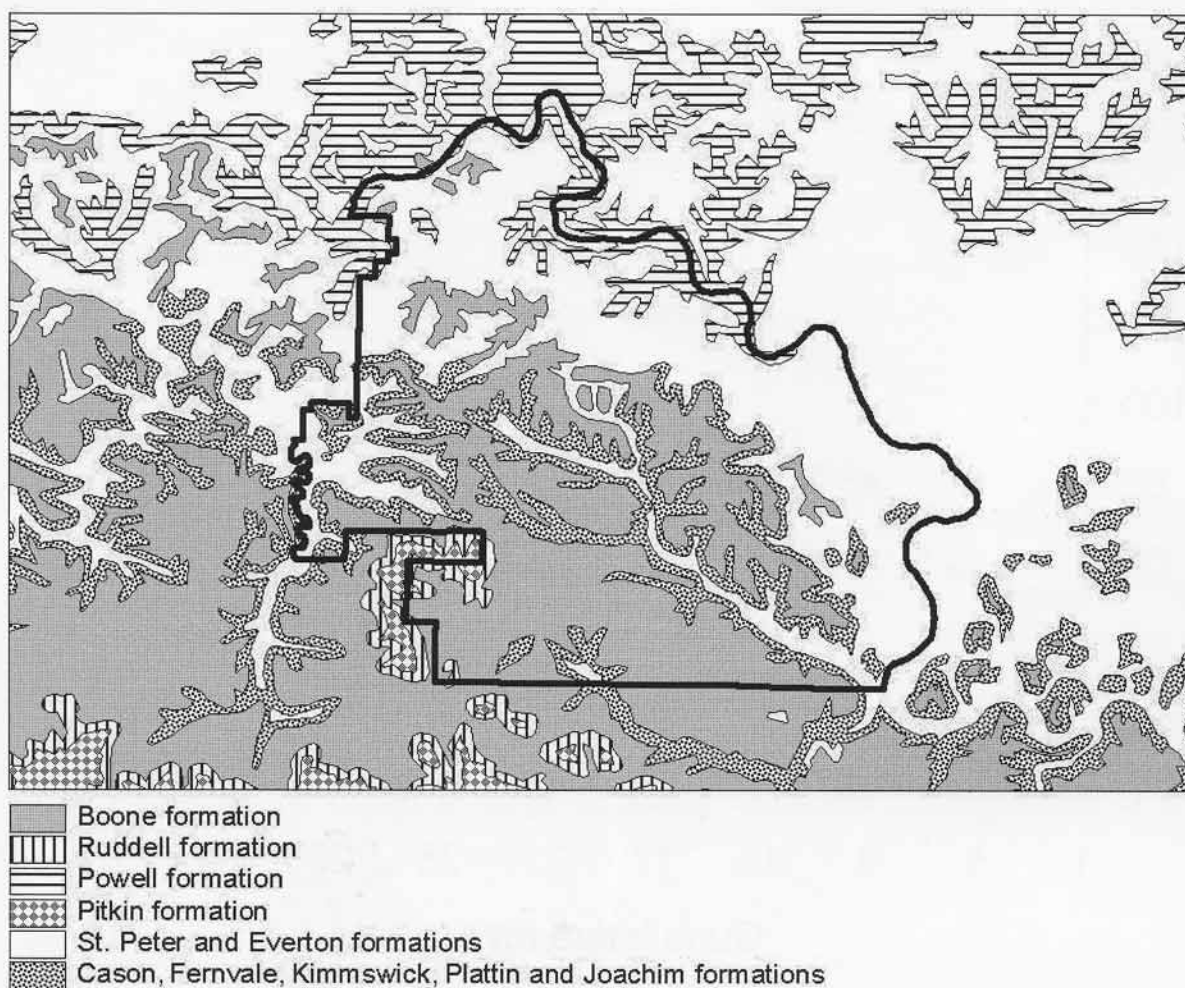


Fig. 2. Surface geology of Sylamore District, adapted from a digital map created by the Arkansas Geologic Commission.

Partee Spring. For flowing cave streams, water samples were collected manually where discharge was greatest for the stream cross-section, and for still water, the samples were collected in the largest accessible pool. The following parameters were analyzed: metals in sediments and water column; nitrate and ammonia-nitrogen, total and orthophosphate, chloride, fluoride, sulfate, and hardness (all in mg/L); total coliform and *Escherichia coli* densities (each as colony-forming unit / 100 mL), temperature (± 0.5 °C); pH (± 0.5 unit); turbidity (± 0.5 Nephelometric Turbidity Unit); and specific conductivity (± 1 μ Siemens/cm). Sampling techniques and analytical procedures followed approved US Environmental Protection Agency methods. Analyses were performed at the Arkansas Department of Environmental Quality's Environmental Chemistry Laboratory, the Arkansas Water Resources Center's Water Quality Laboratory, and the Center of Excellence in Poultry Science's Central Analytical Laboratory. Appropriate

quality assurance and quality control measures were taken.

Biological inventories of macrofauna were performed from September 2000 to December 2002. During this two-year study, over 40 field trips were taken and at least 35 caves and springs were inventoried (Fig. 1). They are: Albino Orchid Cave, Alexander Cave, Almus Knob Cave, Almus Knob Annex Cave, Bald Scrappy Cave, Barfing Vulture Cave, Big Creek Cave, Biology Cave, Bird's Nest Cave, Black Gum Cave, Blanchard Springs Caverns, Blowing Spring Cave, Bonanza Cave, Breakdown Cave, Bud Wallis Cave, Clark Spring – Alexander Cave, Dead Bear Cave, Double Barrel Cave, Gunner Cave, Gustafson Cave, Hammer Springs Cave, Hanger Cave, Herald Hollow Cave, Hidden Spring Cave, Lower Shelter Cave, Norfolk Bat Cave, Optimus Cave, Partee Spring, Rowland Cave, Saltpeter Cave, Shelter Cave, Thruway Cave, Upper Shelter Cave, and Wood's Hollow Caves No. 1 and No. 2. Sites were georeferenced in Universal Transverse Mercator

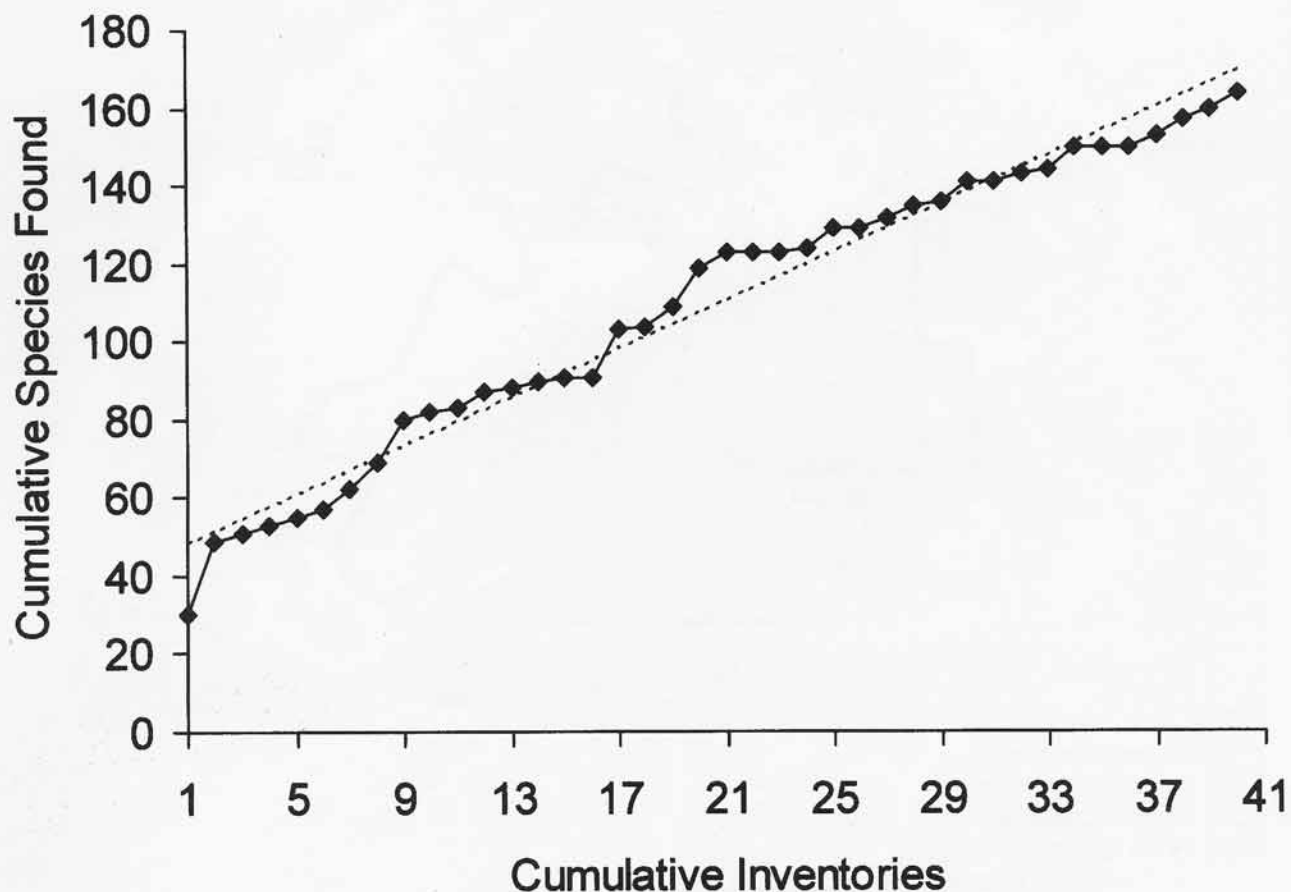


Fig. 3. Collector's curve for this inventory effort (40 bioinventories performed from September 2000 to December 2002), where cumulative number of inventories were plotted against cumulative number of unique species found, with a line fitted to the curve.

coordinates using North America Datum 1983 with a global positioning system handheld unit (Garmin III Plus GPS), and the estimated position error was recorded (range of 1 - 20 m). In each cave surveyed, fauna were inventoried using the most unobtrusive methods possible and at times when endangered bats were not hibernating or birthing. Macrofauna were counted visually with helmet-mounted lights, using snorkeling gear and dive lights for deep pools. For submerged passages, SCUBA was necessary, and those portions of the surveys were sub-contracted to certified cave divers as funds permitted. Collections were limited to those fauna that were impossible to identify on site and were made possible by the following permits: Federal Fish and Wildlife Permits PRT-834518, TE834518-3, TE834518-2 and TE834518-1, Arkansas Natural Heritage Commission Permit S-NHCC-98-009 and S-NHCC-97-009, and Arkansas Game and Fish Commission Educational

Collecting Permits 1082 and 1476. Voucher specimens were collected by hand, aspirator, or net, preserved in 75% ethanol, and brought back to the University of Arkansas at Fayetteville (UAF) for identification and cataloging. Specimens were identified at UAF by Graening and Slay, by Jeffrey Barnes (UAF Dept. of Entomology), or sent to taxonomic specialists, including the following: Kenneth Christiansen (Grinnell College) and Jeffrey Battigelli (Earthworks Research Group) for collembolans; Horton Hobbs III (Wittenburg Univ.) for decapods; John Holsinger (Old Dominion Univ.) for amphipods; Jerry Lewis (Lewis Consulting, Inc.) for isopods; William Shear (Hampden-Sydney College) for diplopods; Jeffrey Battigelli for acari; William Muchmore (University of Rochester) for pseudoscorpions; Henry Robison (Southern Arkansas Univ.) for fishes; Stewart Peck (Carleton Univ.) for coleopterans; James Cokendolpher (Museum of Texas Tech

Univ.) and Darrell Ubick (California Academy of Sciences) for opilionids; Lynn Ferguson (Longwood College) and Mark Muegge (Texas Cooperative Extension) for diplurans; Anne Hampton (Castleton College) for planarians; Theodore Cohn (Univ. of Michigan) for orthopterans; and Gerald Walsh (USEPA, retired) for gastropods. Specimens were curated in the National Museum (Smithsonian Institute), UAF Arthropod Museum, and personal collections of the specialists.

The environmental quality and species' occurrence data were entered into a database (Access 2000, Microsoft, Inc.) and combined with all other available data sources, including the following: Sylamore District cave files (USFS, unpublished data); Cave Research Foundation (Welbourn 1980, 1983); Natural Heritage Database (Arkansas Natural Heritage Commission, unpublished data); and yearly bat surveys (reports by Michael Harvey and Ron Redman to USFS and the Arkansas Game and Fish Commission). Other data sources included: Wilson, 1967; Dickson, 1971; Flemming, 1972; Schuier et al., 1972; McIntosh, 1973; Peck, 1973; Grove, 1974; Grove and Harvey, 1974; Harvey, 1975; McDaniel and Smith, 1976; Muchmore, 1976; Peck and Russell, 1976; Stotler and Crandall-Stotler, 1977; Saugey et al., 1978; Youngsteadt and Youngsteadt, 1978; Darlington and Chandler, 1979; McDaniel et al., 1979; Beck and Dorris, 1982; Dunivan et al., 1982; Waddell, 1982; Smith, 1984; Graening and Brown, 2000; and Graening et al., 2001.

Statistical analyses (using JMP 5, SAS, Inc., software) and geographical information system analyses (using ArcView 3.2, ESRI, Inc., software) were performed to discern any relationships between the distribution and richness of cave fauna and factors such as geologic setting and watershed, water quality, level of disturbance, etc. Statistics used included linear and logistic regression, pairwise correlation, *t*-test, and the chi-square test (where water and sediment quality parameters that were below detection were set to the detection limit). For some of the analyses in this study, data for Rowland Cave and Blanchard Springs Caverns were analyzed separately, and in other instances data were combined. Dye tracing has shown that these two cave systems are hydrologically connected by sharing the same subterranean stream (Aley, 1980), and mapping surveys have converged the systems within 300 feet of a traversable connection. Similarly, data for Clark Spring and Alexander Cave were combined for some analyses because divers have connected the spring resurgence owned by USFS (Clark Spring) to the upstream cave system owned privately (Alexander Cave).

Results

Summary of water and sediment quality analyses are presented in Tables 1 and 2, and the complete data set is available in Graening et al. (2003). Surficial geology was

Table 1. Summary statistics of water quality parameters of select cave streams and springs on the Sylamore District.

Parameter	Unit	n	Min.	Mean	Max.
Temperature	Celsius	8	9.0	13.4	15.0
pH	pH unit	13	5.5	6.5	7.0
Turbidity	NTU	7	1.5	2.7	7.0
Conductivity	µS/cm	16	8	190	305
Chloride	mg/L	16	1.5	3.9	6.1
Fluoride	mg/L	10	0.05	0.06	0.08
Sulfate	mg/L	16	2.45	4.97	8.44
Hardness	mg/L	15	26	115	175
Ortho-phosphate	mg/L	16	0.007	0.024	0.084
Total phosphate	mg/L	7	0.056	0.077	0.111
Ammonia	mg/L	3	0.01	0.01	0.02
Nitrate	mg/L	16	0.07	0.91	3.78
<i>Escherichia coli</i>	CFU/100mL	16	4	79	199
Total coliforms	CFU/100mL	16	20	524	2540

determined for 208 solution caves, one crevice cave, three springs, one sinkhole, two pits, and one bluff shelter by site reconnaissance and by using GIS analyses upon the Arkansas Geologic Commission's digital version of the 1976 Geologic Map of Arkansas, scale 1:500,000 (Fig. 2). Sixty caves were formed in Mississippian Period limestone (Boone formation), 51 were formed in Ordovician limestones and dolomites (Fernvale, Platin, and Joachim formations), and 96 were formed in Ordovician limestone (Everton formation) with a few caves each in other carbonates (Cotter, Jefferson City, Powell formations). Of the 52 mapped caves, mean total passage length was 637 m, the longest cave in the data set was the Rowland – Blanchard Springs Caverns complex at over 17,000 m of combined, mapped passages, and the shortest was Partee Spring at 5 m.

Species occurrence data obtained from our study and others produced a total of 1,238 species occurrences, 230 unique species reported, 61 sites with some amount of species occurrence data, and 40 sites with intensive

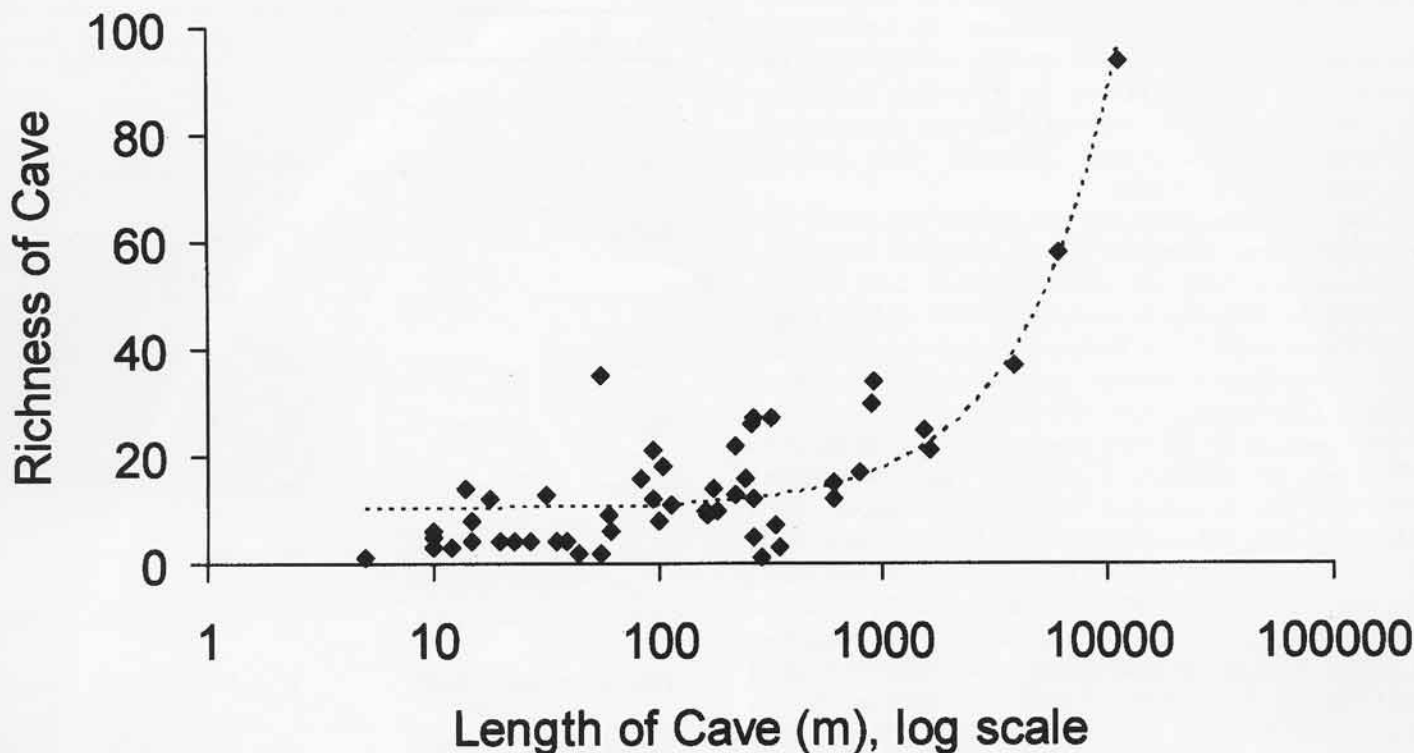


Fig. 4. Total mapped passage lengths (m) of caves in this study were directly proportional to their richness (total number of unique species per cave).

bioinventories - see Graening et al. (2003) for a detailed faunal list. A collector's curve was created, whereby each novel species found during consecutive collecting trips was added to the cumulative number of species found and plotted against cumulative number of collecting trips (Fig. 3) and assuming consistent search effort. The number of cumulative species found increased linearly with every additional inventory (species = $45.235 + 3.111 \times \text{number of inventories}$, $r^2 = 0.973$, $P < 0.001$), suggesting that this study did not exhaustively inventory all animals inhabiting Sylamore District caves.

Of 52 cave habitats with at least partial inventory data, the mean species per habitat (alpha diversity) was 15, with a maximum of 81 (Blanchard Springs Caverns), a median of 12, and a mode of 4. The Rowland Cave - Blanchard Springs Cavern complex was the richest with 96 species, and second was Bud Wallis Cave with 34 species. The relationship between species richness and number of caves having that richness was significant, indicating that an exponentially fewer number of caves have an increasingly greater number of species [$\log(\text{number of caves}) = 0.703 - (0.013 \times \text{richness})$, $n = 29$, $P = 0.006$, $r^2 = 0.252$]. Regional species richness

(gamma diversity) was difficult to estimate, but at least 14 stygobites and troglobites and at least 215 other, non-cave adapted species occurred on the Sylamore District (Table 3). The Rowland-Blanchard Springs Caverns complex had the most obligates per cave with a count of nine. Second were the Clark Spring - Alexander Cave complex and Gunner Cave, both with six, followed by Hammer Spring Cave, Biology Cave, Breakdown Cave, Norfork Bat Cave, and Woods Hollow Cave No. 1, all with four.

The pooled faunal occurrences ($n = 1,238$) were examined for most abundantly occurring species, irrespective of habitat. Overall, arthropods dominated the cave habitats, especially crickets, mosquitoes, spiders, and springtails. The most common invertebrates were cave crickets of the genus *Ceuthophilus* with 59 site occurrences. The most common vertebrates were eastern pipistrelle bats (*Pipistrellus subflavus*) with 41 occurrences and eastern woodrats (*Neotoma floridana*) with 31 occurrences. In aquatic habitats, plethodontid salamanders and crustaceans dominated. Significant species found and their number of occurrences include the following: cave salamander (*Eurycea lucifuga*) - 23 occurrences; grotto salamander (*Typhlotriton*

Table 2. Summary statistics of metals concentrations in water samples (n = 15) and sediment samples (n = 9) in select cave streams and springs on the Sylamore District. Other metal concentrations measured were below detectable limits in water samples - beryllium (< 0.3 µg/L), cadmium (< 0.4 µg/L), and selenium (< 3.0 µg/L) - and in sediment samples - beryllium (< 1 mg/L), cadmium (< 1 mg/L), molybdenum (< 2 mg/L), and selenium (< 0.6 mg/L).

Water														
	As	B	Ba	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	V	Zn
	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min.	---	< 4.5	< 8.8	6.4	---	---	< 0.5	< 15.0	0.8	< 0.5	---	---	---	3.3
Mean	---	69.0	15.2	42.4	---	---	1.5	17.0	2.2	1.0	---	---	---	11.1
Max.	< 1.0	203.8	22.6	53.2	< 0.5	< 1.0	3.9	44.2	13.4	3.4	< 2.5	< 0.6	< 1.0	39.3

Sediment														
	As	B	Ba	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	V	Zn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Min.	< 1	---	4	647	1	< 1	3	1152	260	59	2	2	6	4
Mean	4	---	60	15284	11	5	7	18915	512	10087	27	14	62	33
Max.	11	< 1.0	99	37373	27	15	17	91261	1541	84501	81	27	96	62

spelaeus) - 16 occurrences; cave isopods (*Caecidotea* spp.) - 10 occurrences; and cave amphipods (*Stygobromus* spp.) - 10 occurrences.

Logistic regression of surface geology category by species richness revealed that sites underlain by Ordovician Period formations (Fernvale, Kimmswick, Plattin, and Joachim carbonates) were significantly richer in species than sites underlain by other formations (Boone, Cotter, Jefferson City, or Everton) (n = 52, $P = 0.030$, $r^2 = 0.169$). Analysis revealed that species richness was significantly greater when organics were present (n = 52, $P = 0.001$, $r^2 = 0.222$, $t = -3.795$) and when bat guano was present (n = 52, $P = 0.001$, $r^2 = 0.220$, $t = -3.753$). Species richness did not significantly differ between Buffalo River and Middle White River watersheds ($P = 0.547$), nor by water resource category ($p = 0.383$), nor by degree of recreational use ($P = 0.100$). Species richness of a site was directly proportional to its passage length (m) (richness = $10.067 + 0.007 \times \text{length}$, n = 52, $r^2 = 0.76$, $t = 12.71$, $P < 0.001$); approximately one more species is added for every additional 100 m of cave passage (Fig. 4).

Discussion

A diverse array of arachnids, crustaceans and insects dominate the species composition of cave faunas in

Arkansas (Graening et al., 2001) and in the U.S. in general (Culver et al., 2000). In a survey of cave streams of the Springfield plateau, Willis and Brown (1985) found that isopods (*Caecidotea* spp.) were the most common benthic invertebrates, and chironomids were second. Graening et al. (2001) also found isopods to be the most abundant benthic invertebrates in a survey of Arkansas cave streams, while cave crickets were the most common terrestrial invertebrates and bats and salamanders were the most abundant vertebrates. Similar findings are reported here. The Sylamore District is one of the most biologically important karst areas of the Ozark Plateaus ecoregion. Several species with federal status under the Endangered Species Act rely upon subterranean habitats of the Sylamore District: two endangered bat species, the gray bat (*Myotis grisescens*) and the Indiana bat (*M. sodalis*), utilize many caves for hibernation and reproduction; the endangered Ozark big-eared bat (*Corynorhinus townsendii ingens*) has occasionally been reported in crevice and solution caves; and the endangered Hell Creek cave crayfish (*Cambarus zophonastes*) is rumored to exist in Blanchard Springs Caverns, and its designated habitat (Hell Creek Cave recharge zone) is contiguous with the district boundary. At least 14 subterranean-obligate species exist on the Sylamore District, including two new species of troglotic diplurans

Table 3. At least 16 species are known to be limited to, or adapted to, groundwater habitats (stygobites) or caves (troglobites) on the Sylamore District. Also shown are the global heritage status ranks assigned by The Nature Conservancy and NatureServe: G1- critically imperiled; G2 – imperiled; G3 – vulnerable; G4 – apparently secure; G5 – demonstrably secure; GU – unranked (NatureServe, 2002).

Species	Common Name	Rank
<i>Apochthonius titanicus</i>	Cave false scorpion	G1G2
<i>Caecidotea antricola</i>	Cave isopod	G3G4
<i>Causeyella causeyae</i>	Cave milliped	GU
<i>Causeyella youngsteadtorum</i>	Cave milliped	GU
<i>Hesperochernes occidentalis</i>	Cave false scorpion	G4G5
<i>Litocampa</i> sp. nov. 1	New species of cave dipluran	GU
<i>Litocampa</i> sp. nov. 2	New species of cave dipluran	GU
<i>Phanetta subterranea</i>	Cave spider	G4
<i>Spelobia tenebrarum</i>	Cave dung fly	GU
<i>Stygobromus alabamensis alabamensis</i>	Alabama cave amphipod	G4G5
<i>Stygobromus</i> sp. nov.	Undescribed amphipod	GU
Tricladida	Unidentified cave flatworm	GU
<i>Typhlichthys subterraneus</i>	Southern cavefish	G4
<i>Typhlotriton spelaeus</i>	Grotto salamander	G4

(*Litocampa* spp.) that await taxonomic description. However, the bioinventory effort is far from complete, and much taxonomic study remains to be done. Continuation of biologic and geologic inventories is highly recommended in order to accurately assess and manage these karst resources.

Caves have often been likened to islands due to their insular features, especially their hydrologic and geologic barriers (e.g., Culver, 1970). As a general pattern, larger islands carry more species than smaller ones, and this species-area relationship is well documented in diversity studies (e.g., MacArthur and Wilson, 1967). Similarly, the largest caves (measured as passage length) are often the most diverse - the world's longest cave, Mammoth Cave, at over 571 km of passage, has the greatest known number of stygobites and troglobites (Culver and Sket, 2000). Longer caves imply more habitat types and trophic resources, which may increase the few niches available and increase carrying

capacity (Culver and Sket, 2000). Cave length was significantly correlated to richness in this study and in Arkansas caves in general (Graening et al., 2001). For this reason, length was used as the primary criterion for biological significance ranking. However, this constitutes a significant management challenge because the longest caves are usually the most attractive for recreational caving. The richness of obligate species is often used to rank the importance of the world's caves (e.g. Culver and Sket, 2000), and this criterion was also used in this study. The third criterion was total species richness, which is a common measure of biological significance, and in this study, significantly fewer caves had high species counts. The 61 caves that had been bioinventoried adequately were ranked according to these three criteria if they had a minimum of at least two obligate species, at least 20 total species, and at least 600 m of cave passage (Table 4). The Rowland Cave-

Blanchard Springs Caverns complex ranked highest with 96 species (Table 5), nine of which were stygobites or troglobites.

The best-studied caves tend to be the most biologically rich caves (see summary by Graening et al., 2001). Blanchard Springs Caverns is undoubtedly Arkansas' most thoroughly studied cave, although we agree with McIntosh (1973) who states, "*The inventory of biologic features of Blanchard Springs Caverns will never be complete.*" Ignoring this and other biases, this cave complex is the most species rich cave documented in Arkansas to date and second only to Tumbling Creek Cave, Taney County, Missouri, for the entire Ozark plateaus ecoregion; Tumbling Creek Cave has approximately 105 species, 12 of which are stygobites or troglobites (William Elliot, pers. comm.). Blanchard Springs Caverns also has at least two single-site endemics - a liverwort, *Plagiochila acanthophylla ciliigera*, (Stotler and Crandall-Stotler, 1977) and a cellular slime mold, *Dictyostelium caveatum*, (Waddell, 1982). Surprisingly, it is also a very impacted cave. Blanchard Springs Caverns is the most visited cave in Arkansas with an estimated 88,000 visitors per year (Bob Reeves, Caverns Administrator, pers. comm.). It has been modified in many ways including the paving of passages, extensive illumination of surfaces, and the creation of two artificial entrances and other tunnels and shafts by use of explosives.

The impact of trespass, archaeological looting, and vandalism in caves of the Sylamore District is of special concern. Approximately 30 recreational caving permits per year and 50 scientific study permits per year are issued, and Tinkle estimates over 100 recreational caving trips per year are undertaken illegally (without permits). The Arkansas Cave Resources Protection Act of 1989 affords limited protection to caves, and subterranean fauna are protected by Arkansas Game and Fish Commission Regulation No.1817 - Wildlife Pet Restrictions and the federal Endangered Species Act of 1973. Protection for Arkansas caves also necessitates the enforcement of state and federal water quality and solid waste disposal regulations, although water and sediment analyses of the study caves did not reveal any major pollution concerns on the Sylamore District. The Federal Cave Resources Protection Act protects caves designated as "significant" on federal lands by allowing federal land managers to keep cave locations and names confidential and assign a penalty of up to \$10,000 for abuses. All surveyed caves on the Sylamore District have been designated "significant." All caving and related activities on Forest Service lands are by permit only and permits can be acquired by contacting the District Office.

Other management recommendations include increasing protection of vulnerable, high-ranking sites, such as Alexander Cave which is not under public ownership, and the improvement of public outreach regarding wise use of karst resources. The USFS has invested approximately

0.6 million dollars in protection of karst resources on the Sylamore District, including the following: endangered bat species monitoring and research at approximately \$10,000 per year for at least 12 years; four cave gates at approximately \$50,000 each; monitoring, research, and educational products at approximately \$15,000 per year for the last 10 years; and \$102,000 spent on the protection, development, and maintenance of Blanchard Springs Caverns since its dedication, and another \$35,000 was spent for research and continuing water and air quality monitoring.

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Literature Cited

- Aley, T. 1980. Delineation of the recharge area for Blanchard Springs: the identification, location, and evaluation of water quality hazard areas. Report to the U. S. Forest Service, Mountain View, Arkansas.
- Beck, M., and P. Dorris. 1982. A continuation of spider research in Arkansas: east central Ozark Mountain Area. Proc. Ark. Acad. Sci. 36:20-22.
- Culver, D. C. 1970. Analysis of simple cave communities I: Caves as islands. Evolution 24:463-474.
- Culver, D. C., and B. Sket. 2000. Hotspots of subterranean biodiversity in caves and wells. Jour. Cave. Karst Stud. 62:11-17.
- Culver, D. C., L. Master, M. Christman, and H. Hobbs III. 2000. The obligate cave fauna of the 48 contiguous United States. Conserv. Biol. 14: 386-401.
- Darlington, J., and C. Chandler. 1979. A survey of the

- planarians (Tricladida: Paludicola) of Arkansas. Southw. Nat. 24(1):141-148.
- Dickson, J. W.** 1971. The reptiles of the Sylamore Ranger District, Ozark National Forest, Arkansas. Unpubl. Masters Thesis, Memphis State University, Memphis, Tennessee.
- Dunivan, J. D., C. R. Tumilson, and V. R. McDaniel.** 1982. Cave fauna of Arkansas: further records. Proc. Ark. Acad. Sci. 36:87-88.
- Flemming, L.** 1972. The evolution of the eastern North American isopods of the genus *Asellus* (Crustacea: Asellidae) Part I. Int. Journ. Speleol. 4:22-256.
- Graening, G. O., and A. V. Brown.** 2000. Status survey of aquatic cave fauna in Arkansas. A report submitted to the Arkansas Game and Fish Commission. Publication No. MSC-286. Arkansas Water Resources Center, University of Arkansas, Fayetteville. 44 pp.
- Graening, G. O., M. E. Slay, and A. V. Brown.** 2001. Subterranean biodiversity in the Ozark Plateaus of Arkansas. A report submitted to Arkansas Game and Fish Commission and Arkansas Department of Natural Heritage. University of Arkansas, Fayetteville. 28 pp.
- Graening, G. O., M. E. Slay, and K. K. Tinkle.** 2003. Bioinventory and bioassessment of caves in the Sylamore Ranger District, Ozark National Forest, Arkansas. Final report to the U. S. Forest Service, Mountain View, Arkansas. 35 pp.
- Grove, J.** 1974. Ecology of Blanchard Springs Caverns, Ozark National Forest, Arkansas. Masters thesis, Memphis State University, Memphis, Tennessee. 27 pp.
- Grove, J., and M. J. Harvey.** 1974. Ecology of Blanchard Springs Caverns, Ozark National Forest, Arkansas. Report to the U. S. Forest Service, Mountain View, Arkansas.
- Harris, K.** 2003. The top twenty cave states in the United States by length. Nat. Speleol. Soc. News 61: 25-26.
- Harvey, M. J.** 1975. Distribution and ecology of vertebrates inhabiting caves of the Sylamore Ranger District, Ozark National Forest. Report to the U. S. Department of Agriculture, Forest Service, Ozark National Forest, Mountain View, Arkansas. 35 pp.
- MacArthur, R., and E. Wilson.** 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.
- Malard, F., S. Plenet, and J. Gibert.** 1996. The use of invertebrates in groundwater monitoring: a rising research field. Groundw. Mon. Remed. 16:103-113.
- McDaniel, V. R., and K. L. Smith.** 1976. Cave fauna of Arkansas: selected invertebrate taxa. Proc. Ark. Acad. Sci. 30:57-60.
- McDaniel, V. R., K. Paige, and C. R. Tumilson.** 1979. Cave fauna of Arkansas: additional invertebrate and vertebrate records. Proc. Ark. Acad. Sci. 33:84-85.
- McIntosh, P.** 1973. Inventory of biological features of Blanchard Springs Caverns. Unpubl. report. US Forest Service, Mountain View, Arkansas.
- Muchmore, W. B.** 1976. New species of *Apochthonius*, mainly from caves in central and eastern United States (Pseudoscorpionida, Chthoniidae). Proc. Biol. Soc. Wash. 89:67-80.
- NatureServe.** 2002. NatureServe Explorer: An online encyclopedia of life. Version 1.6. NatureServe, Arlington, Virginia. URL: <http://www.natureserve.org/explorer>.
- Peck, S. B.** 1973. A systematic revision and the evolutionary biology of the *Ptomaphagus* (Adelops) beetles of North America (Coleoptera; Leiodidae; Catopinae), with emphasis on cave-inhabiting species. Bull. Mus. Comp. Zoology 145:29-162.
- Peck, S. B., and D. Russell.** 1976. Life history of the fungus gnat *Macrocera nobilis* in American caves (Diptera: Mycetophilidae). Can. Ent. 108:1235-1241.
- Saughey, D., R. Baber, and V. McDaniel.** 1978. An unusual accumulation of bat remains from an Ozark cave. Proc. Ark. Acad. Sci. 32:92-93.
- Schuijer, J. P., J. W. Dickson, and M. J. Harvey.** 1972. Herpetofauna of Sylamore Ranger District, Ozark National Forest, Arkansas: preliminary report. Proc. Ark. Acad. Sci. 26:61-66.
- Smith, K. L.** 1984. The status of *Cambarus zophonastes* Hobbs and Bedinger, an endemic cave crayfish from Arkansas. Arkansas Natural Heritage Commission. Little Rock, Arkansas. 15 pp.
- Stein, B. A., L. S. Kutner, and J. S. Adams, editors.** 2000. Precious heritage: the status of biodiversity in the United States. The Nature Conservancy and Association for Biodiversity Information. Oxford University Press, New York, New York. 399 pp.
- Stotler, R., and B. Crandall-Stotler.** 1977. A checklist of liverworts and hornworts of North America. Bryologist 76:405-428.
- Waddell, D. R.** 1982. A predatory slime mold. Nature 298:464-466.
- Welbourn, W. C.** 1980. Summary report for the cave resource inventory on the Sylamore District, Ozark-St. Francis National Forest. Prepared for the US Dept. of Agriculture, Forest Service, Mountain View, Arkansas. Cave Research Foundation, Dallas, Texas.
- Welbourn, W. C.** 1983. Summary report for the cave resource inventory on the Sylamore District, Ozark-St. Francis National Forest, Part 2. Prepared for the USDA, Forest Service, Mountain View, Arkansas. Cave Research Foundation, Dallas, Texas.
- Willis, L. D., and A. V. Brown.** 1985. Distribution and habitat requirements of the Ozark cavefish (*Amblyopsis rosae*). Am. Mid. Nat. 114:311-317.
- Wilson, S. N.** 1967. Faunal collections in Blanchard Springs Caverns with some ecological notes. Unpubl. report. U. S. Forest Service, Ozark National Forest, Mountain

View, Arkansas. 8 pp.

Youngsteadt, N. W., and J. O. Youngsteadt. 1978. A survey of some invertebrates from northern Arkansas. The Association for Arkansas Cave Studies, Inc. Arkansas Cave Studies, Number 1. 13 pp.

Table 4. Ranking of the top 20 most biologically significant caves on the Sylamore District, with and without Blanchard Springs Caverns and Rowland Cave combined. Sites were scored according to the following formula: (number of obligate species x 10) + (number of total species) + (square root of length in meters).

Site Name	No. of obligates	No. of Species	Length	Score	Rank
Rowland – BSC Cave complex	9	96	17381	318	1 st
Blanchard Springs Caverns	8	81	11265	267	1 st
Rowland Cave	7	58	6116	206	2 nd
Clark Spring – Alexander Cave	6	29	5633	164	3 rd
Gunner Cave	6	31	3891	153	4 th
Norfolk Bat Cave	4	27	900	97	5 th
Biology Cave	4	17	789	85	6 th
Bonanza Cave	2	24	1536	83	7 th
Gustafson Cave	2	33	906	83	7 th
Hammer Springs Cave	4	25	321	83	7 th
Hidden Spring Cave	2	21	1629	81	8 th
Breakdown Cave	4	15	605	80	9 th
Big Creek Cave	3	27	265	73	10 th
Saltpeter Cave	3	11	900	71	11 th
Herald Hollow Cave	3	24	262	70	12 th
Woods Hollow Cave No. 1	4	18	105	68	13 th
Bud Wallis Cave	2	34	55	61	14 th
Bald Scrappy Cave	2	22	220	57	15 th
Woods Hollow Cave No. 2	3	16	84	55	16 th
Double Barrel Cave	2	21	94	51	17 th
Panther Mountain Cave	2	9	167	42	18 th

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Table 5. All known animal species (96) found in Rowland – Blanchard Springs Cavern complex, with obligate species emboldened (data from this study and those cited in Methods). Columns are scientific name of species, common name of species, degree of adaptation to subterranean environments (obligate – troglobite or stygobite; tolerant – troglophile or stygophile; intolerant or transitory – incidental; or unknown), and site of species' occurrence – Blanchard Springs Caverns (BSC), Rowland Cave, or both caves.

Species	Common Name	Adaptation	Site
<i>Achaearanea tepidariorum</i>	Common house spider	Troglophile	BSC
<i>Aecothea specus</i>	Cave fly	Troglophile	BSC
<i>Agkistrodon contortrix contortrix</i>	Southern copperhead	Incidental	Rowland Cave
<i>Ambystoma maculatum</i>	Spotted salamander	Troglophile	BSC
<i>Amoebalaria defessa</i>	Fly	Troglophile	Both
Amphipoda - stygophilic	Surface amphipod	Stygophile	BSC
<i>Apochthonius titanicus</i>	Cave false scorpion	Troglobite	BSC
<i>Arrhopalites clarus</i>	Springtail	Troglophile	Rowland Cave
<i>Athetini</i> sp.	Rove beetle	Unknown	Rowland Cave
<i>Bibio albipennis</i>	Beetle	Unknown	BSC
<i>Brevicornu</i> sp.	Fungus gnat	Unknown	BSC
<i>Caecidotea antricola</i>	Cave isopod	Stygobite	Rowland Cave
Calliphoridae	Unidentified blow fly	Unknown	BSC
<i>Camponotus americanus</i>	Ant	Unknown	BSC
<i>Causeyella causeyae</i>	Cave milliped	Troglobite	Both
<i>Ceuthophilus gracilipes</i>	Cave cricket	Troglophile	Both
Chironomidae	Unidentified blood worm	Unknown	Both
Chrysomelidae sp. 1 and 2	Unidentified beetles	Unknown	BSC
Corynoptera sp.	Dark-winged fungus gnat	Troglophile	Both
Curculionidae	Unidentified weevil	Unknown	BSC
Decapoda - crayfish	Unidentified crayfish	Stygophile	BSC
<i>Drosophila melanogaster</i>	Fruit fly	Unknown	BSC
<i>Elaphe obsoleta</i>	Black rat snake	Incidental	BSC

Species	Common Name	Adaptation	Site
<i>Eptesicus fuscus</i>	Big brown bat	Troglophile	Both
<i>Eurycea longicauda melanopleura</i>	Dark-sided salamander	Troglophile	Both
<i>Eurycea lucifuga</i>	Cave salamander	Troglophile	Both
<i>Eurycea multiplicata multiplicata</i>	Many-ribbed salamander	Troglophile	BSC
<i>Exechia</i> sp.	Fungus gnat	Unknown	BSC
<i>Exechiopsis</i> sp.	Fungus gnat	Unknown	Rowland Cave
Formicidae	Unidentified ant	Unknown	BSC
Gastropoda - aquatic snail	Unidentified aquatic snail	Unknown	BSC
Ichneumonidae	Unidentified wasp	Incidental	BSC
<i>Lasionycteris noctivagans</i>	Silver-haired bat	Troglophile	Rowland Cave
<i>Lasiurus borealis</i>	Eastern red bat	Troglophile	Both
<i>Lasiurus cinereus</i>	Hoary bat	Troglophile	Both
<i>Leiobunum</i> sp.	Eastern harvestman	Troglophile	BSC
Lepidoptera	Unidentified moth	Unknown	BSC
<i>Leptocera caenosa</i>	Small dung fly	Unknown	BSC
<i>Leptoneta arkansa</i>	Spider	Troglophile	BSC
<i>Ligidium elrodii elrodii</i>	Sow bug	Troglophile	BSC
Lithobiomorpha	Unidentified centipede	Unknown	BSC
<i>Litocampa</i> sp. nov. 1 and 2	New species cave diplurans	Troglobite	Rowland Cave
Lumbricidae	Unidentified earthworm	Troglophile	Both
<i>Macrocera nobilis</i>	Fungus gnat	Troglophile	Both
<i>Megapallifera ragsdalei</i>	Ozark mantleslug	Unknown	BSC
<i>Megaselia cavernicola</i>	Humpbacked fly	Troglophile	Rowland Cave
<i>Mephitis mephitis</i>	Striped skunk	Incidental	Rowland Cave
<i>Microtus pinetorum</i>	Woodland vole	Troglophile	BSC
<i>Mus musculus</i>	House mouse	Troglophile	BSC

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Species	Common Name	Adaptation	Site
<i>Myotis grisescens</i>	Gray bat	Troglophile	Both
<i>Myotis lucifugus</i>	Little brown bat	Troglophile	Both
<i>Myotis septentrionalis</i>	Northern long-eared bat	Troglophile	Both
<i>Myotis sodalis</i>	Indiana bat	Troglophile	Both
Nematomorpha	Horsehair worm	Unknown	BSC
<i>Neotoma floridana</i>	Eastern woodrat	Troglophile	Rowland Cave
<i>Nycticeius humeralis</i>	Evening bat	Troglophile	Rowland Cave
<i>Patera perigrapta</i>	Engraved bladetooth snail	Unknown	BSC
Pentatomidae	Unidentified stinkbug	Unknown	BSC
<i>Pericoma signata</i>	Dark-winged fungus gnat	Unknown	BSC
<i>Phagocata gracilis</i>	Flatworm	Stygophile	BSC
Phoridae	Humpbacked fly	Unknown	BSC
<i>Pipistrellus subflavus</i>	Eastern pipistrelle	Troglophile	Both
<i>Platynus</i> sp.	Ground beetle	Troglophile	BSC
Plecoptera	Stonefly larva	Unknown	BSC
<i>Plethodon albagula</i>	Slimy salamander	Troglophile	BSC
<i>Plethodon angusticlavius</i>	Ozark zigzag salamander	Troglophile	BSC
<i>Procyon lotor</i>	Northern raccoon	Troglophile	Rowland Cave
<i>Pseudopolydesmus pinetorum</i>	Milliped	Troglophile	BSC
<i>Psychoda satchelli</i>	Moth fly	Unknown	BSC
<i>Ptomaphagus cavernicola</i>	Round fungus beetle	Troglophile	Rowland Cave
<i>Rana catesbeiana</i>	BullFrog	Incidental	BSC
<i>Rana clamitans melanota</i>	Green frog	Incidental	BSC
<i>Rana sphenoccephala</i>	Southern leopard frog	Incidental	BSC
<i>Rana sylvatica</i>	Wood frog	Incidental	BSC
<i>Rhagidia</i> sp.	Mite	Unknown	Rowland Cave

Species	Common Name	Adaptation	Site
<i>Sabacon cavicolens</i>	Harvestman	Troglophile	Rowland Cave
<i>Sayornis phoebe</i>	Eastern phoebe	Troglophile	Both
Sciaridae	Dark-winged fungus gnat	Unknown	BSC
<i>Sciurus carolinensis</i>	Eastern gray squirrel	Incidental	BSC
Soricidae	Shrew	Troglophile	BSC
<i>Spelobia tenebrarum</i>	Cave dung fly	Troglomite	Rowland Cave
Sphingidae	Unidentified sphinx moth	Unknown	BSC
<i>Storeria occipitomaculata</i>	Red-belly snake	Incidental	BSC
<i>Stygobromus a. alabamensis</i>	Alabama cave amphipod	Stygobite	BSC
<i>Stygobromus</i> sp. nov.	Undescribed cave amphipod	Stygobite	Rowland Cave
<i>Tamias striatus</i>	Eastern chipmunk	Incidental	BSC
Tipulidae	Unidentified crane fly	Troglophile	Both
Tomoceridae	Unidentified springtail	Unknown	BSC
Trichoceridae	Winter crane fly	Incidental	BSC
Turbellaria	Stream flatworm	Stygophile	BSC
<i>Typhlotriton spelaeus</i>	Grotto salamander	Troglomite	Both
<i>Ventridens ligera</i>	Globose dome snail	Unknown	BSC
<i>Virginia valeriae</i>	Smooth earth snake	Incidental	BSC
<i>Zonitoides arboreus</i>	Quick gloss snail	Unknown	Rowland Cave